PROBLEMS

1. If one mole of ethane gas (C_2H_6) is burned in oxygen to $CO_2(g)$ and $H_2O(l)$, with the simultaneous release of 1560 kJ at standard state conditions, what is the value of ΔH_f° for C_2H_6?

   ΔH_f° for $H_2O(l) = -285.8$ kJ/mol $\qquad \Delta H_f^\circ$ for $CO_2(g) = -393.7$ kJ/mol

2. The standard enthalpy of formation of $NH_3(g)$ is –46.0 kJ/mol. Calculate the thermal energy evolved when 8.0 g of $H_2(g)$ react with an excess of $N_2(g)$.

3. Find the standard enthalpy of formation of $CH_4(g)$ given the following data.

   $CH_4(g) + 2\,O_2(g) \longrightarrow CO_2(g) + 2\,H_2O(l) \qquad \Delta H^\circ = -891.2$ kJ

   $C(s) + O_2(g) \longrightarrow CO_2(g) \qquad \Delta H^\circ = -393.7$ kJ

   $H_2(g) + {}^1/_2\,O_2(g) \longrightarrow H_2O(l) \qquad \Delta H^\circ = -285.8$ kJ

4. When 50.0 mL of 0.50 M $NH_3(aq)$ is mixed with 50.0 mL of 0.50 M HCl(aq), the temperature of the mixed solutions rises from 21.3°C to 24.4°C. Calculate the ΔH°_{rxn} for

   $NH_3(aq) + HCl(aq) \longrightarrow NH_4Cl(aq)$

5. Find ΔH°_{rxn} for the reaction

   $$2\,N_2(g) + 5\,O_2(g) \longrightarrow 2\,N_2O_5(g)$$

   using the standard enthalpies of reaction below.

   $2\,H_2(g) + O_2(g) \longrightarrow 2\,H_2O(l) \qquad \Delta H^\circ_{rxn} = -571.6$ kJ

   $N_2O_5(g) + H_2O(l) \longrightarrow 2\,HNO_3(l) \qquad \Delta H^\circ_{rxn} = -76.6$ kJ

   $N_2(g) + 3\,O_2(g) + H_2(g) \longrightarrow 2\,HNO_3(l) \qquad \Delta H^\circ_{rxn} = -348.2$ kJ

6. Iron metal reacts with oxygen forming iron(III) oxide.

   $4\,Fe(s) + 3\,O_2(g) \longrightarrow 2\,Fe_2O_3(s) \qquad \Delta H^\circ = -1648.4$ kJ

   How much heat energy is produced when 45.4 g of iron undergo reaction?

7. When 0.800 g of Mg is added to 250.0 mL of 0.40 M HCl(aq), the temperature of the mixture rises from 23.4°C to 37.9°C. Determine the enthalpy change for the reaction represented by the equation below.

   $$Mg(s) + 2\,HCl(aq) \longrightarrow H_2(g) + MgCl_2(aq)$$

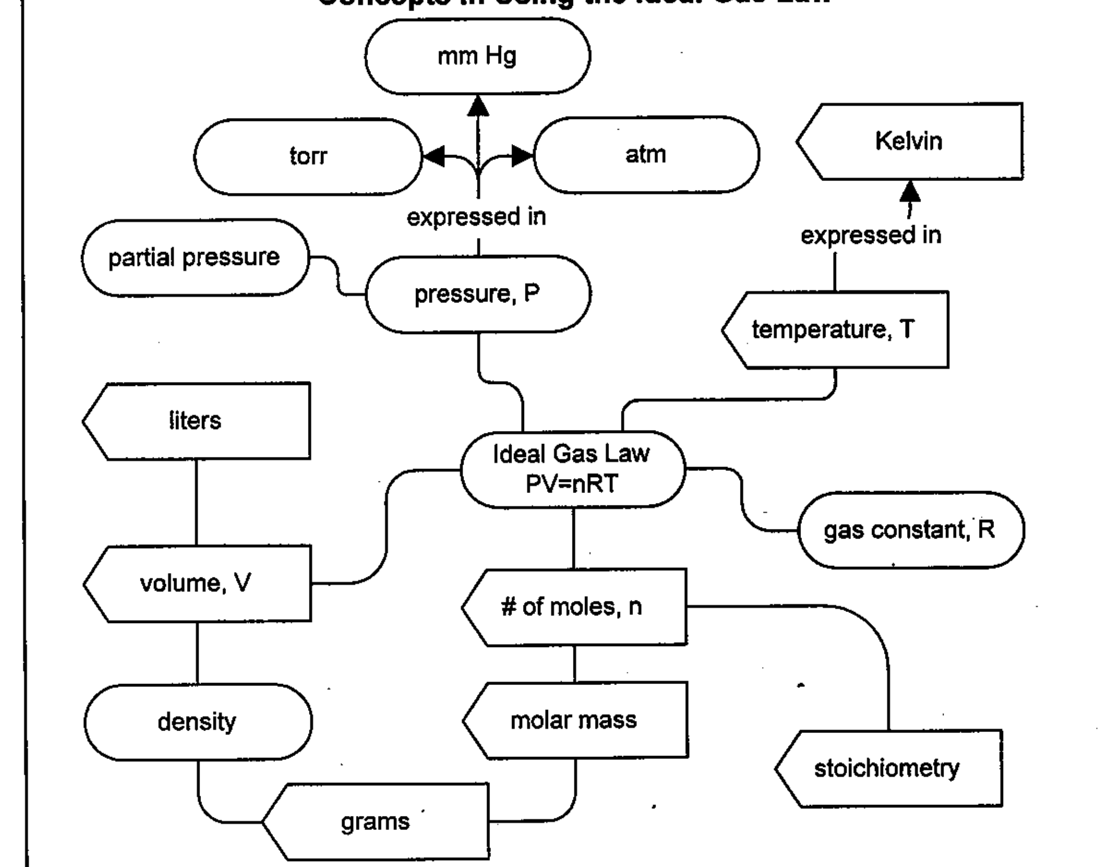
8. When 100.0 mL of 1.0 M HCl is mixed with 100.0 mL of 1.0 M NaOH solution, both at a temperature of 20.4°C, they react as described by the chemical equation below. What is the final temperature of the mixture when the reaction is complete?

   $HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l) \qquad \Delta H^\circ = -58.7$ kJ

USING THE IDEAL GAS LAW

This lesson deals with:

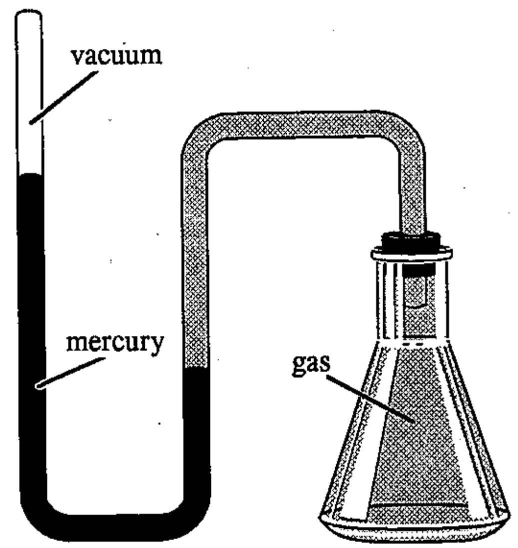
1. Using the ideal gas law to find the pressure, temperature, volume, or amount of a gas when three of these quantities are known.
2. Determining the final conditions of a gas when the initial conditions and the changes are known.
3. Calculating the density of a gas at given conditions.
4. Calculating the molar mass of a gas.
5. Finding the pressure or amount of a gas in a mixture using Dalton's Law of Partial Pressures.



Concepts in Using the Ideal Gas Law

THE PROPERTIES OF GASES

A gas takes both its shape and its volume from its container.
Properties of gases: pressure, volume, temperature.



Pressure

Pressure is force per area.

A **manometer** is a pressure-measuring device made of a glass tube containing mercury. Gas exerts pressure on one side of mercury, pushing it up into the other side. The weight of the mercury lifted is equal to the force exerted by the gas.

weight of mercury = force of gas

The weight of mercury is proportional to its height in the tube.
The difference in the levels of the mercury is proportional to the pressure of the gas.

1 mm Hg = 1 torr
1 atmosphere = 760 mm Hg = 760 torr

International System:

1 Newton/meter^2 = 1 Pascal
1 atmosphere = 1.013×10^5 Pascal

Volume

Most commonly measured in liters.

Temperature

Temperature must be expressed in absolute units.
The temperature scale must start with zero.
The Kelvin scale will be used.

To convert Celsius to Kelvin, add 273 to the Celsius temperature:

$$0°C + 273 = 273 \text{ K}$$

THE IDEAL GAS EQUATION

$$PV = nRT$$

P: pressure
V: volume
n: moles
T: temperature

} variables

R: a constant

The value of *R* depends on the units used for *P*, *V*, and *T*. When P is in atmospheres, V in liters, and T in Kelvin, then

$$R = 0.0821 \text{ L atm / mol K}$$

Other values of R are listed in the table of constants at the back of the Workbook.

Example 1

A 500.0 mL bottle contains hydrogen gas at 605 torr pressure at 18°C. How many moles of hydrogen gas does the bottle contain?

1. Identify the known values of the variables.

   $P = 605$ torr $\quad T = 18°C$
   $V = 500.0$ mL $\quad n$: to be found

2. Make sure the units of *P*, *V*, and *T*, agree with those of *R*.

$$R = 0.0821 \text{ L atm/mol K}$$

$$V = 500.0 \text{ mL} \left(\frac{1 \text{ L}}{1000 \text{ mL}}\right) = 0.5000 \text{ L}$$

$$P = 605 \text{ torr} \left(\frac{1 \text{ atm}}{760 \text{ torr}}\right) = 0.796 \text{ atm}$$

$$T = 18°C + 273.15 = 291 \text{ K}$$

3. Substitute the known values into the ideal gas law equation, and solve for the unknown variable.

$$PV = nRT$$

$$n = \frac{PV}{RT}$$

$$= \frac{(0.796 \text{ atm})(0.5000 \text{ L})}{(0.0821 \text{ L atm/mol K})(291 \text{ K})}$$

$$= 1.67 \times 10^{-2} \text{ mol}$$

Exercise One

A 50.0-liter tank designed to hold 250.0 moles of helium gas can withstand a maximum pressure of 200.0 atmospheres. At what temperature would the tank reach its maximum pressure?

PROBLEMS INVOLVING CHANGES IN CONDITIONS

$$PV = nRT$$

Solve the equation for the constant R.

$$R = \frac{PV}{nT}$$

Because R is constant, the ratio $\frac{PV}{nT}$ is also a constant.

Therefore, when a gas undergoes a change from state 1 to state 2, the ratio remains constant.

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

Example 2

What is the volume of a gas at standard 0°C and 1 atm, if its volume at 142°C and 476 torr is 38.0 mL?

1. Identify the known values of the variables.

state 1	state 2
$P_1 = 476$ torr	$P_2 = 1$ atm
$V_1 = 38.0$ mL	$V_2 = ?$
$T_1 = 142°C = 415$ K	$T_2 = 0°C = 273$ K

Because no gas is added or removed, the number of moles does not change, so $n_1 = n_2$.

2. Convert each variable to the same units.

   $P_1 = 476$ torr $P_2 = 760$ torr

3. Substitute the values into the equation:

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

because $n_1 = n_2$, $$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{(476\text{ torr})(38.0\text{ mL})}{415\text{ K}} = \frac{(760\text{ torr})\,V_2}{273\text{ K}}$$

$$V_2 = \frac{(476\text{ torr})(38.0\text{ mL})(273\text{ K})}{(415\text{ K})(760\text{ torr})} = 15.6\text{ mL}$$

Exercise Two

A small canister of gas has a pressure of 25 atm at 22°C. What would be the pressure in the canister, if it were taken out of doors on a day when the outside temperature was –26°C?

GAS DENSITY

Density is mass per volume (mass divided by volume).

$$\text{density} = d = \frac{m}{V}$$

The Ideal Gas Law equation relates the number of moles of gas to its pressure, temperature, and volume.

$$n = \frac{PV}{RT}$$

The number of moles of a substance is equal to its mass, m, divided by its molar mass, M. That is, $n = m/M$. Therefore,

$$\frac{m}{M} = \frac{PV}{RT}$$

Then, the density of a gas is

$$d = \frac{m}{V} = \frac{MP}{RT}$$

Example 3

What is the density of CO_2 at 22°C and 1.0 atm?

$$d = \frac{MP}{RT}$$

$P = 1.0$ atm
$T = 22°C = 295$ K
$M = 44$ g/mol
Use $R = 0.0821$ L atm/mol K

$$d = \frac{(44 \text{ g/mol})(1.0 \text{ atm})}{(0.0821 \text{ L atm/mol K})(295 \text{ K})}$$

$$= 1.8 \text{ g/L}$$

Exercise Three

Which is denser, helium gas at 1.0 atm and 0°C, or nitrogen gas at 55 torr and 200°C?

MOLAR MASS OF A GAS

By replacing n in the Ideal Gas Law equation with the ratio of mass to molar mass (m/M), we get an equation that involves the molar mass of a gas.

$$PV = \frac{m}{M}RT$$

This can be solved for an equation that relates the molar mass of a gas to its mass, pressure, temperature, and volume of a gas.

$$M = \frac{mRT}{PV}$$

This allows the determination of the molar mass of a gas from measurements of its mass, temperature, pressure, and volume.

Example 4

Vapor fills a flask with a volume of 109.0 mL at a temperature of 97°C and a pressure of 741.5 torr. The mass of the vapor is 0.1673 grams. What is the molar mass of the vapor?

$$M = \frac{mRT}{PV}$$

Identify the four needed values: mass, temperature, pressure, and volume.

$$m = 0.1673 \text{ g}$$

$$T = 97°\text{C} + 273.15 = 370 \text{ K}$$

$$P = 741.5 \text{ torr}\left(\frac{1 \text{ atm}}{760 \text{ torr}}\right) = 0.9756 \text{ atm}$$

$$V = 109.0 \text{ mL}\left(\frac{1 \text{ L}}{1000 \text{ mL}}\right) = 0.1090 \text{ L}$$

Choose a gas constant value with the same units and solve for M.

$$R = 0.0821 \text{ L atm/mol K}$$

$$M = \frac{(0.1673 \text{ g})(0.0821 \text{ L atm/mol K})(370 \text{ K})}{(0.9756 \text{ atm})(0.1090 \text{ L})}$$

$$= 47.8 \text{ g/mol}$$

Exercise Four

When 0.527 gram of a substance is vaporized, it occupies a volume of 135 mL at 98°C and 756.3 torr. What is the molar mass of this substance?

GASEOUS MIXTURES

For a mixture of nitrogen, oxygen, and carbon dioxide, the total number of moles is the sum of the moles of each gas in the mixture.

$$n_{\text{total}} = n_{N_2} + n_{O_2} + n_{CO_2}$$

From the Ideal Gas Law Equation for this mixture,

$$P_{\text{total}} = n_{\text{total}} RT/V$$
$$= (n_{N_2} + n_{O_2} + n_{CO_2})(RT/V)$$
$$= n_{N_2}(RT/V) + n_{O_2}(RT/V) + n_{CO_2}(RT/V)$$
$$= P_{N_2} + P_{O_2} + P_{CO_2}$$

Dalton's Law of Partial Pressures:
The total pressure of a mixture of gases is the sum of the pressures of the individual gases.

Example 5

Some solid $CaCO_3$ was sealed into a 250-mL flask along with argon gas at a pressure of 610 torr at 22°C. The flask was heated and some of the $CaCO_3$ decomposed, giving off CO_2 gas.

$$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$$

After the flask had cooled to 22°C, the pressure was 840 torr. How many moles of CO_2 were produced?

The moles of CO_2 are related to the pressure of CO_2 in the flask.

$$n_{CO_2} = \frac{P_{CO_2} V}{RT}$$

The increase in pressure is due to the CO_2. The pressure of the CO_2 is

$$P_{CO_2} = 840 \text{ torr} - 610 \text{ torr} = 230 \text{ torr}$$

$$P_{CO_2} = 230 \text{ torr}\left(\frac{1 \text{ atm}}{760 \text{ torr}}\right) = 0.30 \text{ atm}$$

$$V = 250 \text{ mL}\left(\frac{1 \text{ L}}{1000 \text{ mL}}\right) = 0.25 \text{ L}$$

$$T = 22°C + 273.15 = 295 \text{ K}$$

$$n_{CO_2} = \frac{(0.30 \text{ atm})(0.25 \text{ L})}{(0.0821 \text{ L atm/mol K})(295 \text{ K})}$$
$$= 3.1 \times 10^{-3} \text{ moles}$$

Exercise Five

A 40.0-liter tank contains a gas at 1820 torr and 23°C. What would be the pressure in the tank if 0.500 mole of gas were added to the cylinder without changing the temperature?

PROBLEMS

1. A gas occupies 85 mL at 0°C and 710 torr. What temperature would be required to increase the pressure to 760 torr with the volume remaining constant?

2. The volume of a gas mixed with water vapor at 32.0°C at 742 torr is 1350 mL. What would be the volume of the gas at 0.0°C and 760 torr if all the water vapor were removed? The pressure of water vapor at 32°C is 36 torr.

3. A 2.00-g sample of a gas occupies 1.09 liters at 28°C and 702 torr. What is the molar mass of the gas?

4. What volume is occupied by 10.0 g of nitrogen gas at 25°C and 835 torr?

5. A cylinder containing 23.5 moles of nitrogen gas has a volume of 9.81 liters. What is the pressure of the gas at 23°C?

6. A flask contains 28.6 g of SO_2 gas. At 40°C, the pressure of the gas is 850 torr. What is the volume of the flask?

7. When the pressure of argon gas is 6.43 atm, at what Celsius temperature will its density be 10.3 g/L?

8. The density of an unknown gas is 1.31 g/L at 749 torr and 20.0°C. What is the molar mass of the gas?

9. A cruise ship is propelled by steam-driven turbines. Superheated steam (steam at a temperature above the boiling point of water) enters the turbine at 371°C and 51 atm. When it exits the turbine, a liter of this superheated steam will have expanded to 153 liters at 131 torr. What is the Celsius temperature of the steam as it exits the turbine?